Crew Exploration Vehicle Project Office

Orion Multi-Purpose Crew Vehicle Drogue Parachute Performance

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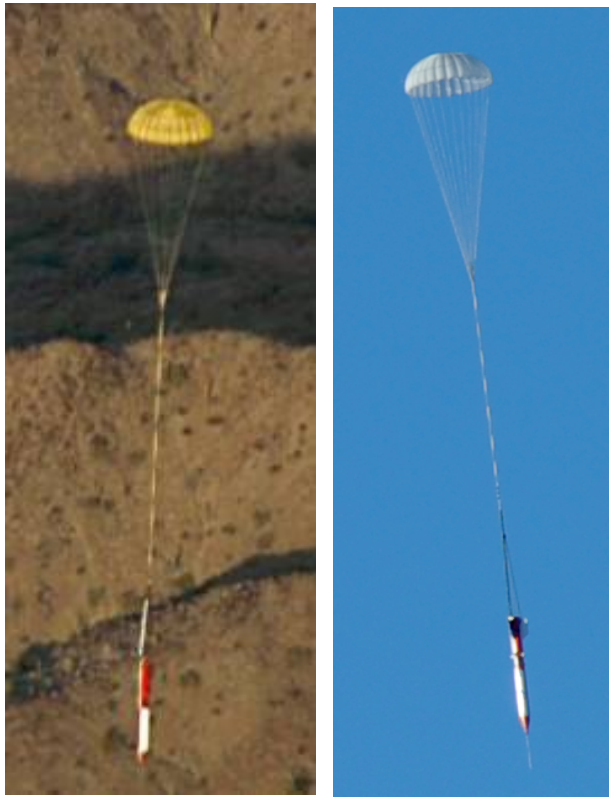
Test Program Motivation

- Orion wake drogue Interaction is not well quantified wrt parachute performance
- Parachute system design (textiles and trailing distance) parameters related to this are not supported by data for the CPAS configuration
- Risk reduction and mass optimization could be achieved in quantification of this environment and validation of codes used in the design process
- Data from a subscale test can support / optimize the full scale test design *at very low cost*
- CFD-FSI Simulations of the CPAS parachute system are being performed to provide insight into the aerodynamics in parachutes in supersonic flow but have not been validated
- Techniques developed can be leverage by future NASA parachute design and analysis efforts



Flight Tests are not performed in representative wake

Test Requirements and Diagnostics

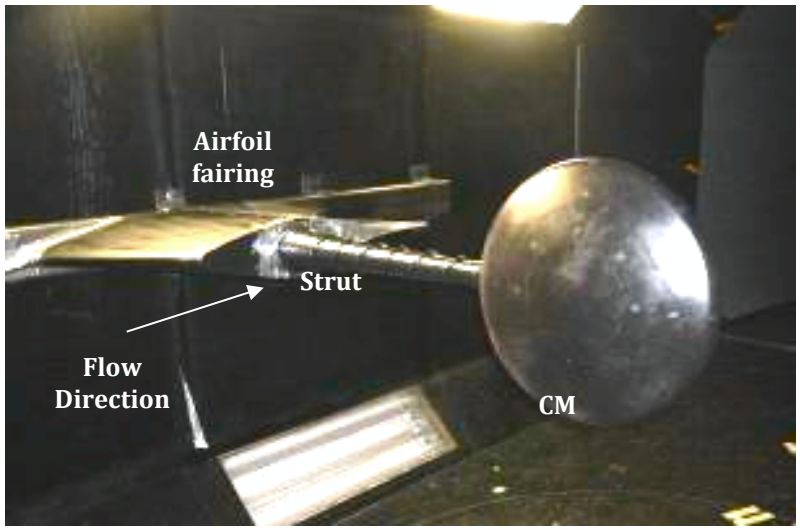
- Simulate flight like wake in a subscale environment (Re, Q)
- Achieve geometric and construction similarity to the full-scale article
- Minimize effects of wind tunnel blockage
- Minimize Aerodynamic Interference
- High spatial resolution
- Quantitative measurement of flow-field
- Time resolved measurements
- Physical insight into the flow-field
- Heritage from past NASA parachute developments
- CFD validation can be the focus

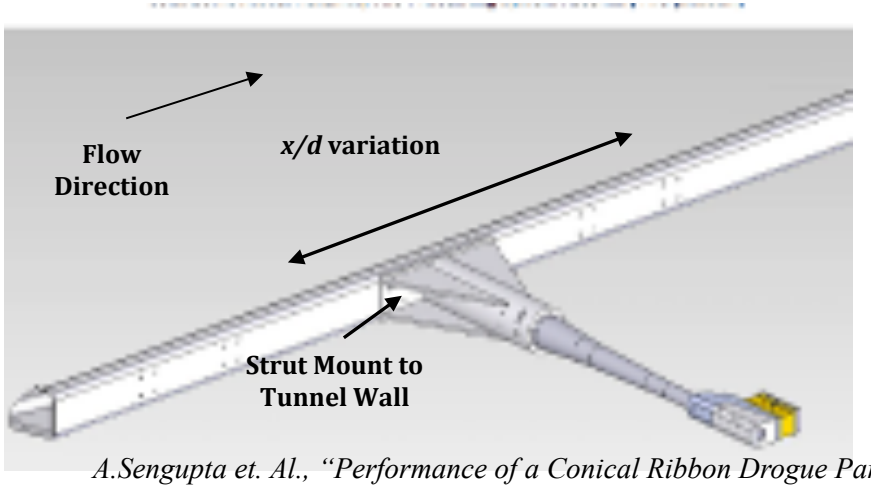
Technique	Parameter
Parachute Load Cell	Parachute aero
Force balance	Capsule aero
PIV	3D Flow field
High Speed Video	Shape reconstruction Dynamic motion
Pressure Sensors	Pressure distribution

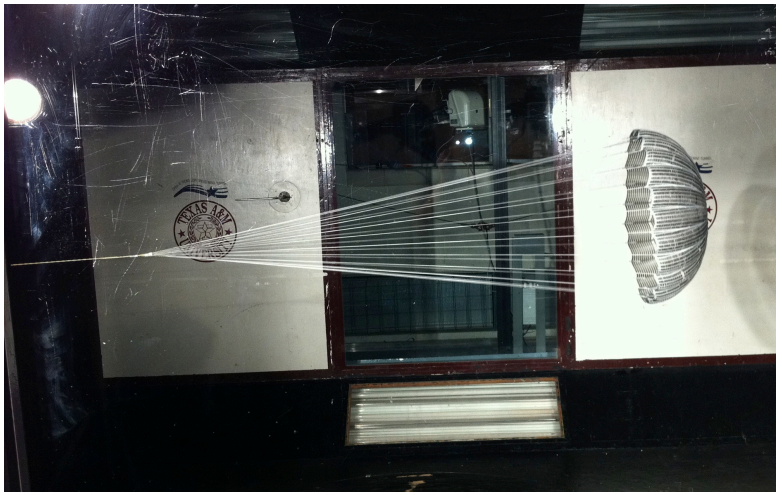
A.Sengupta et. Al., "Performance of a Conical Ribbon Drogue Parachute in the Wake of a Subscale Orion Command Module," IEEE Aerospace Conference, Big Sky MT, March 2012.

Test Facility: Texas A&M

- Tunnel is closed loop atmospheric
- Capable of 4778 Pa (100 psf) dynamic pressure (Re=2x10^6)
- Test section: 3x2.1x5.5 m (10x7x20 ft)
- Clear walls for optical access
- Model was mounted from the side wall on a steel strut
  - Translates axially for x/d variation
  - Rotates with respect to wall mount for capsule angle of attack







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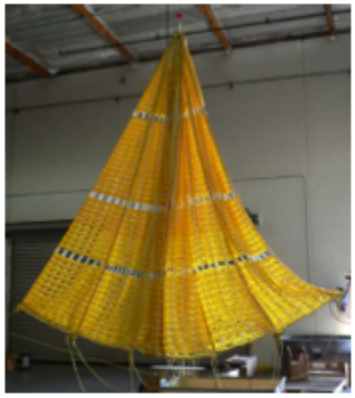
Parachute Test Article

- 10% of full scale conical ribbon drogue
  - Do=0.7m (2.3 ft)
  - Nylon and spectra construction
  - Laser cut gore to simulate ribbons
  - 1st, and 2nd stage reefing was accomplished with a skirt reefing line

Parameter	Symbol	Full Scale	Subscale
Parachute Type	---	VPCR	VPCR
Nominal Diameter (m)	D_o	7	0.7
Number of Gores	---	24	24
Number of Ribbons	---	52	52
Geometric Porosity	---	19.2%	19%
Trailing Distance	x/d	6	6-9.5
Reefing Ratio (%)	RR	50-70	50-70
Reynolds Number (x10^6)	Re	1-7	$\leq$3
Dynamic Pressure (kPa)	Q	1.4-8	0.1-4.8
Mach Number	M	0.1-0.7	0.1-0.3

Subscale Gore Layout



Full Scale

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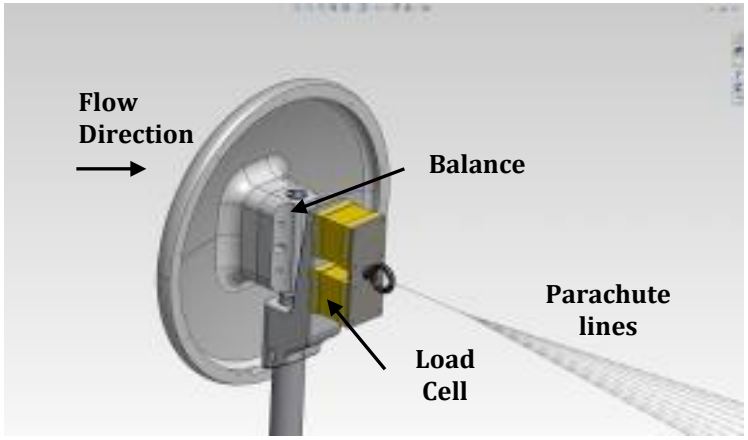
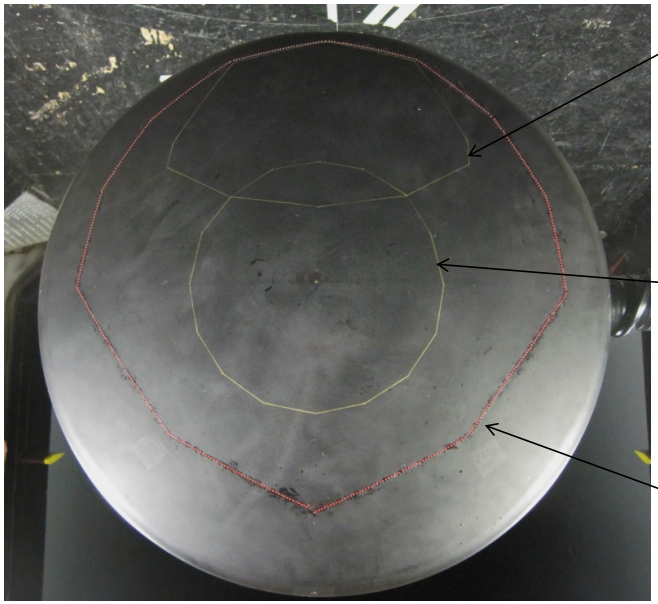
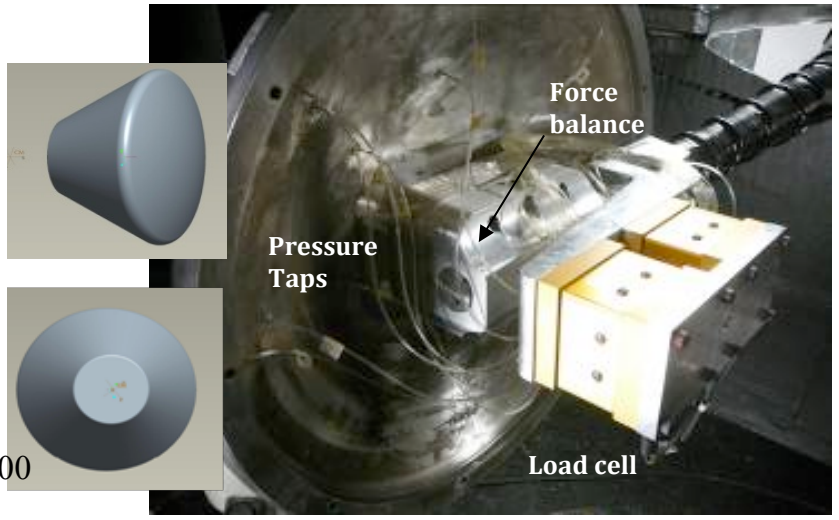
CM Test Article

- 10% scale 0.49-m diameter Command Module (CM)
- Trip dots to control/force transition
- Capsule aero with internal force balance verified with IR thermography
- Parachute aero with load cell
- Capsule rotated on sting to explore 0, 30, and 50 deg angle of attack relative to the free stream (180, 150, 130 pitch plane)







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Test Matrix

- Test matrix explored several parameters
  - Full open, 1st, and 2nd stage reefed configurations
  - Capsule angle of attack range of 0, 30, and 50 degree angle of attack relative to the free-stream
  - Dynamic pressure from 10 to 100 psf explored (Re from 100,000 to 3,000,000)
  - Trailing distance from x/d of 6. 8, and 9.5
  - Capsule laminar to turbulent transition verified with IR thermography

Table 1. Subscale test matrix.

Configuration	d (m)	D_o (m)	x/d	β (deg)	Q_{max} (Pa)	Re_{max}	*Diagnostic*
Capsule Only	0.49	N/A	4, 6, 8, 9.5	0, 30, 50	4778	$3x10^6$	PIV, IR, balance
Unreefed		0.7	6, 8, 9.5	0, 30, 50		$3x10^6$	Balance, load cell
1 stage reefed			6, 8, 9.5	0, 30, 50		$3x10^6$	Balance, load cell
2nd stage reefed			6, 8, 9.5	0, 30		$3x10^6$	Balance, load cell
Constrained			6, 8	0		$2x10^6$	PIV, Balance, load cell

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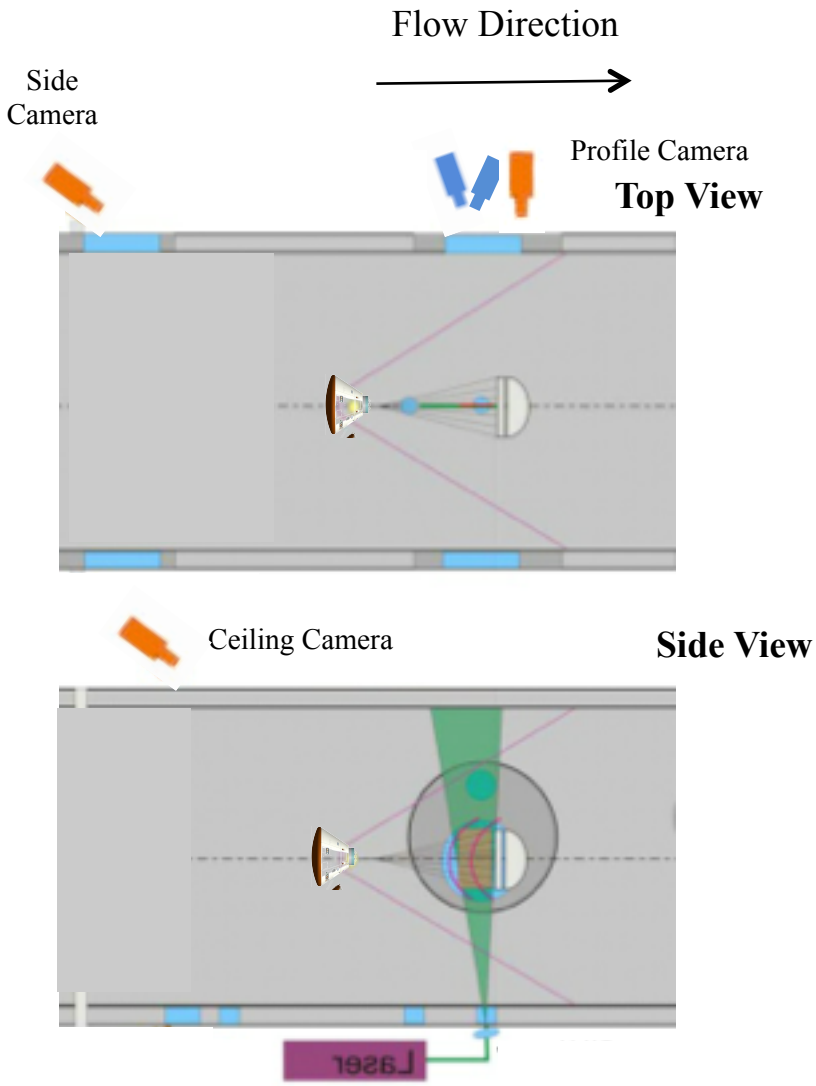
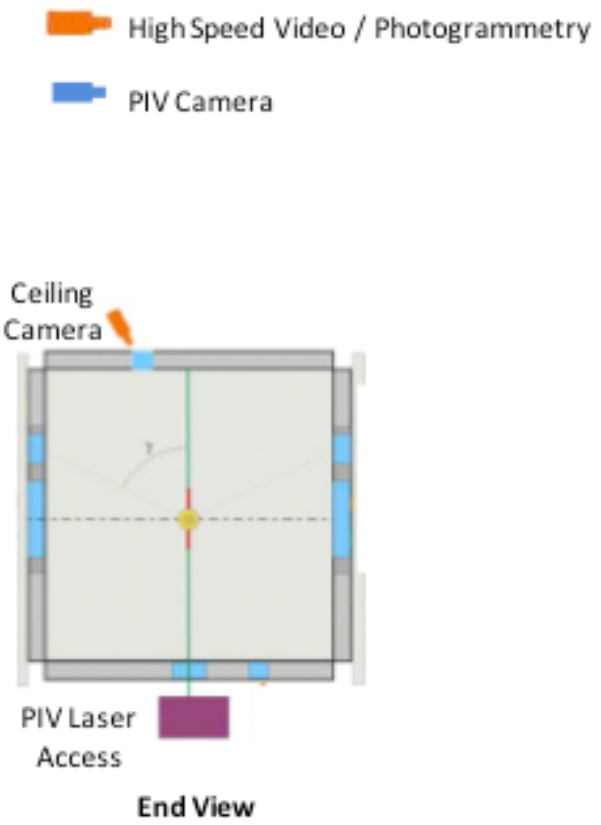
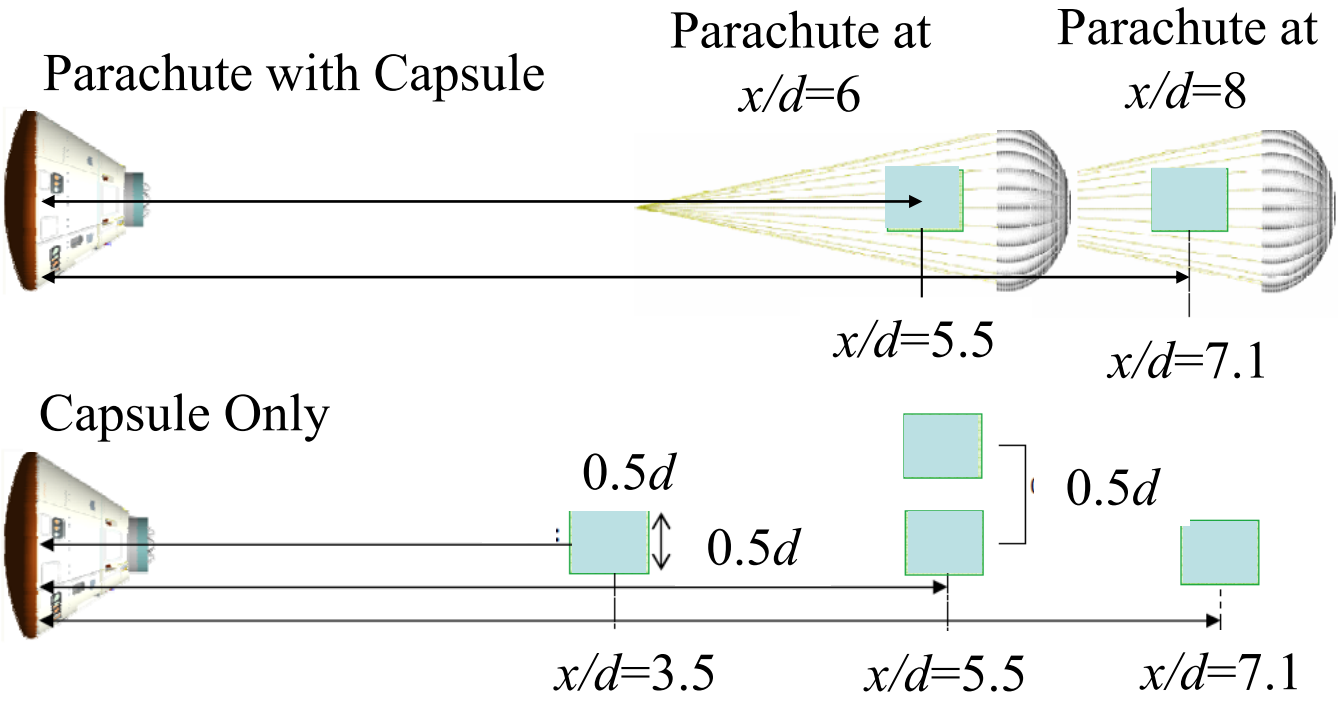
TAMU Optical Diagnostics Layout





Particle Image Velocimetry (PIV)

- High spatial resolution velocimetric measurement
  - 3 components of velocity and turbulence statistics
  - Ideal measurement for CFD validation
- Flow seeding accomplished with mineral oil vaporization
- Measurement conduct at several locations downstream of CM with and without parachute present in the tunnel



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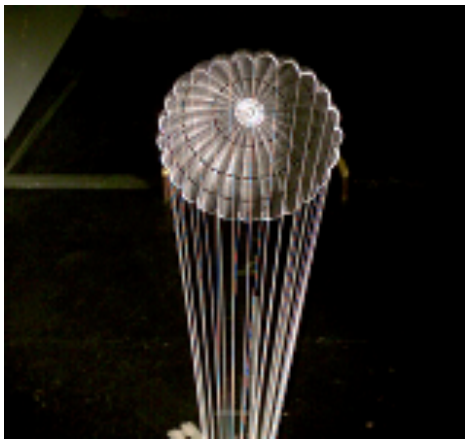
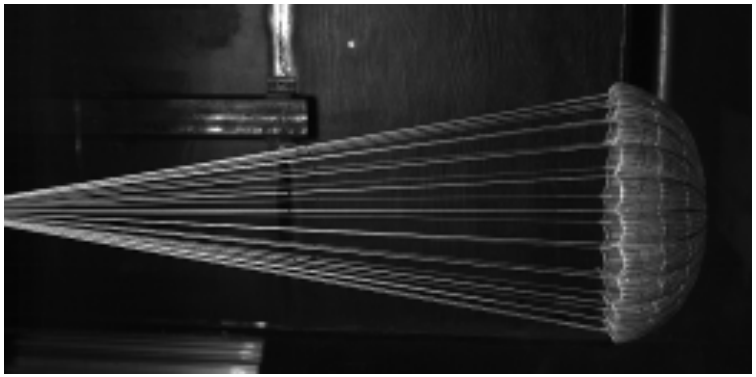
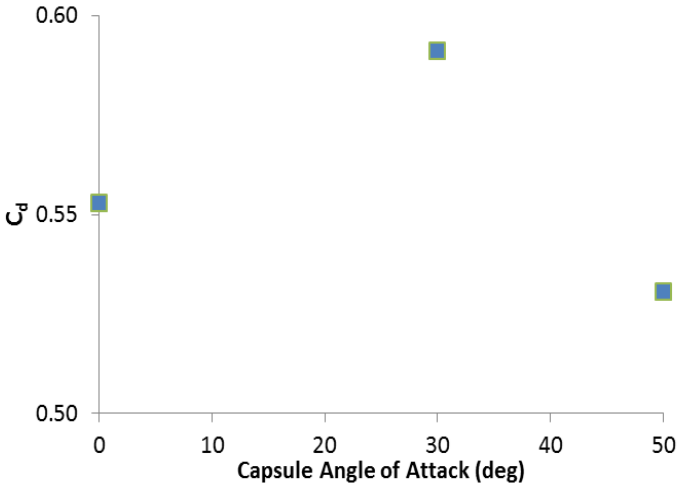
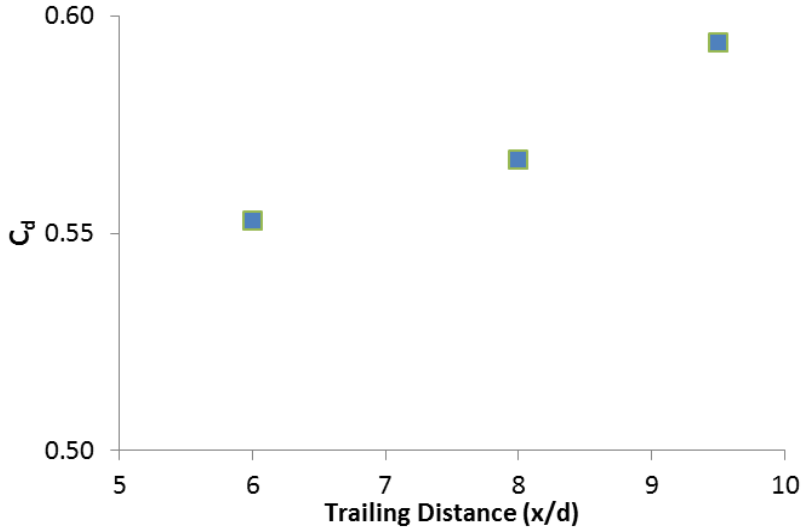
Unreefed Parachute Drag Measurement

- Observations
  - Maximum drag as 30 deg AOA
  - Increase in drag with x/d









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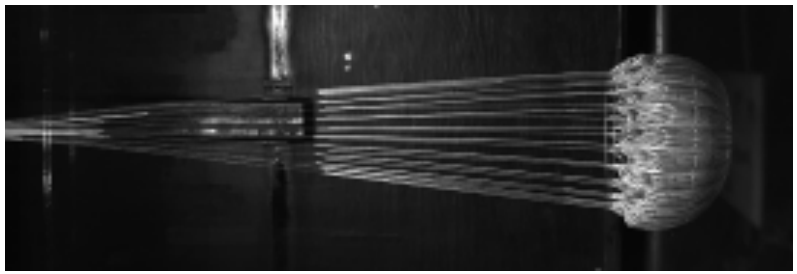
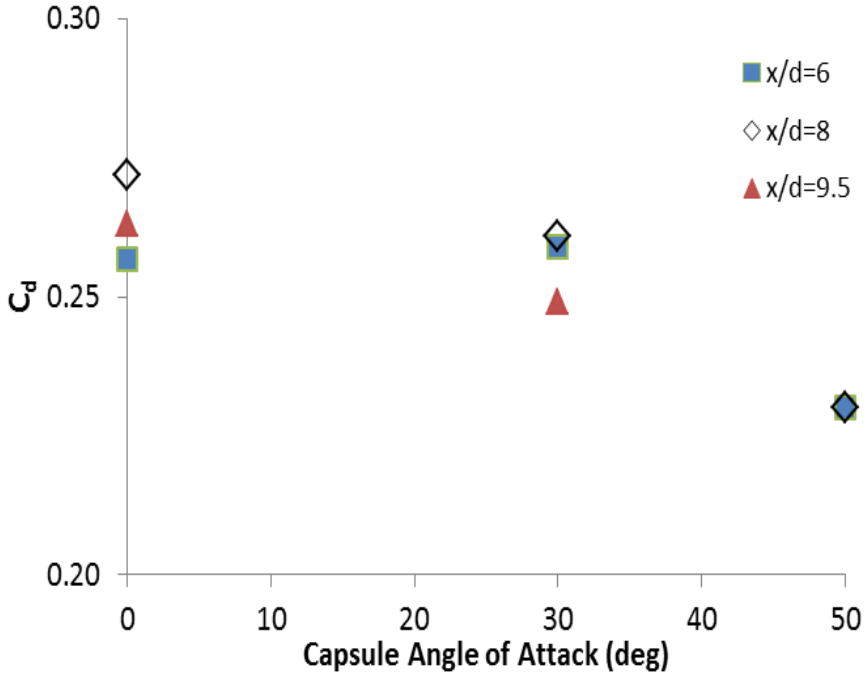
1st Stage Parachute Drag Measurement

- Observations
  - Reduction in drag with AOA
  - Less motion than unreefed
  - More skirt motion





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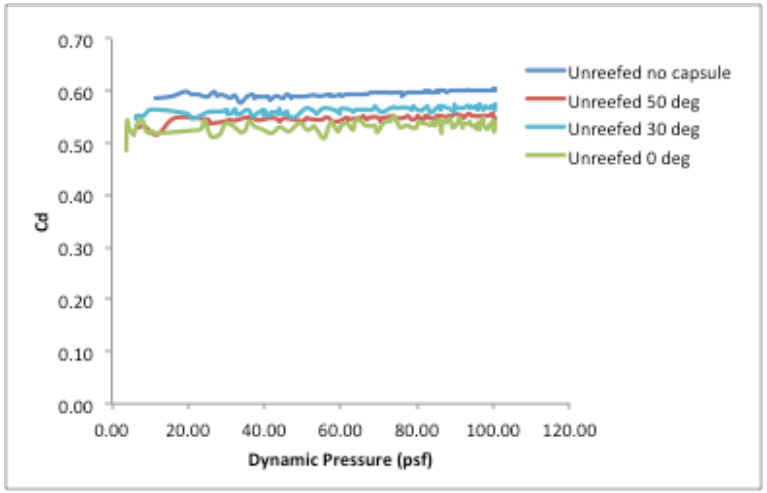
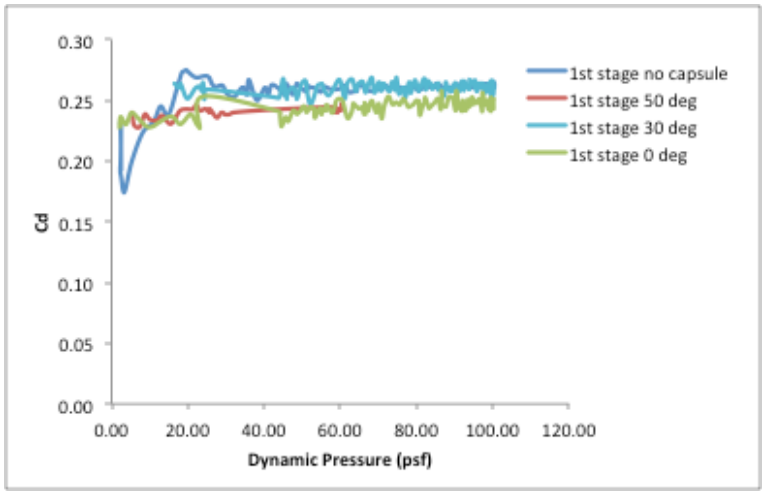
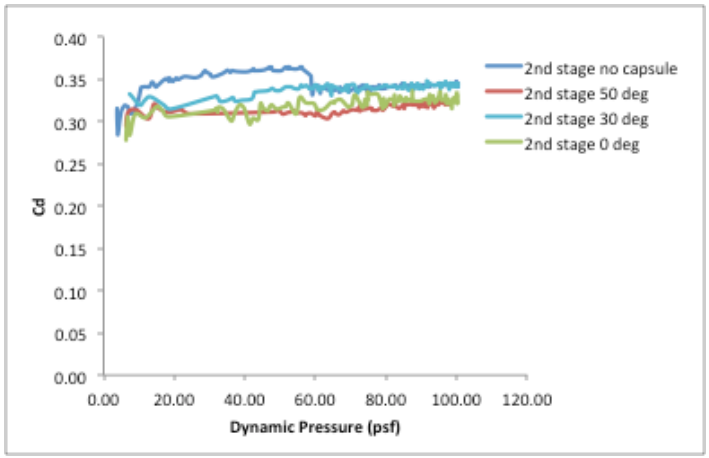
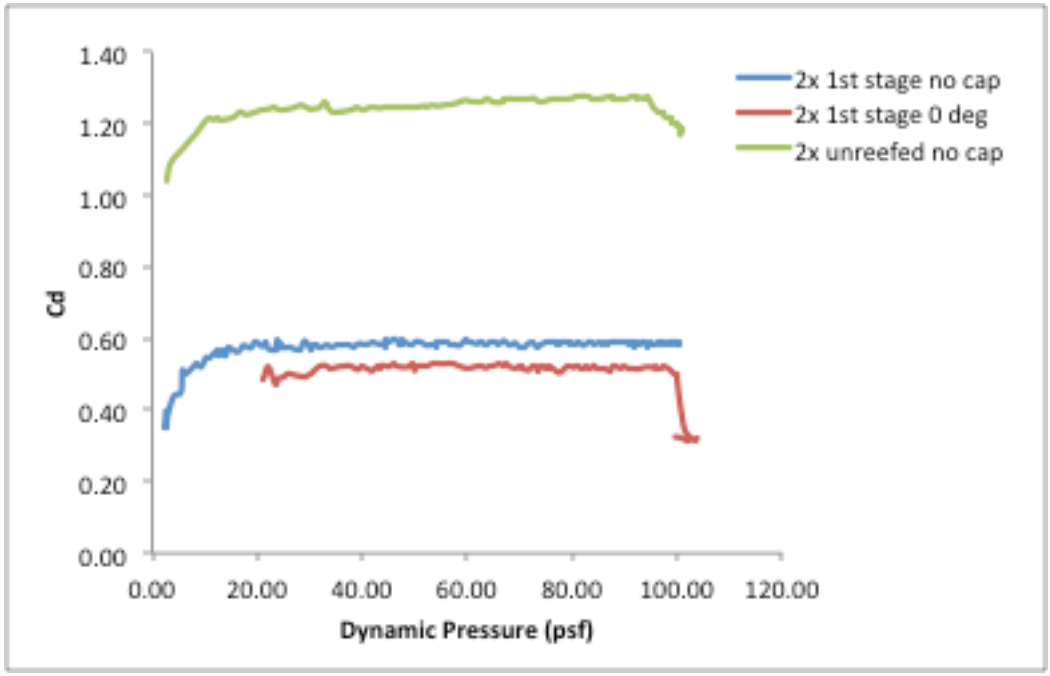
Drag Versus Dynamic Pressure



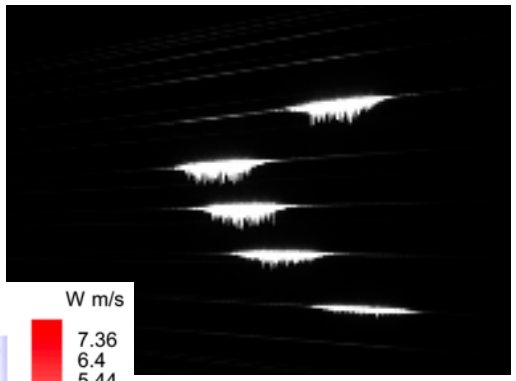




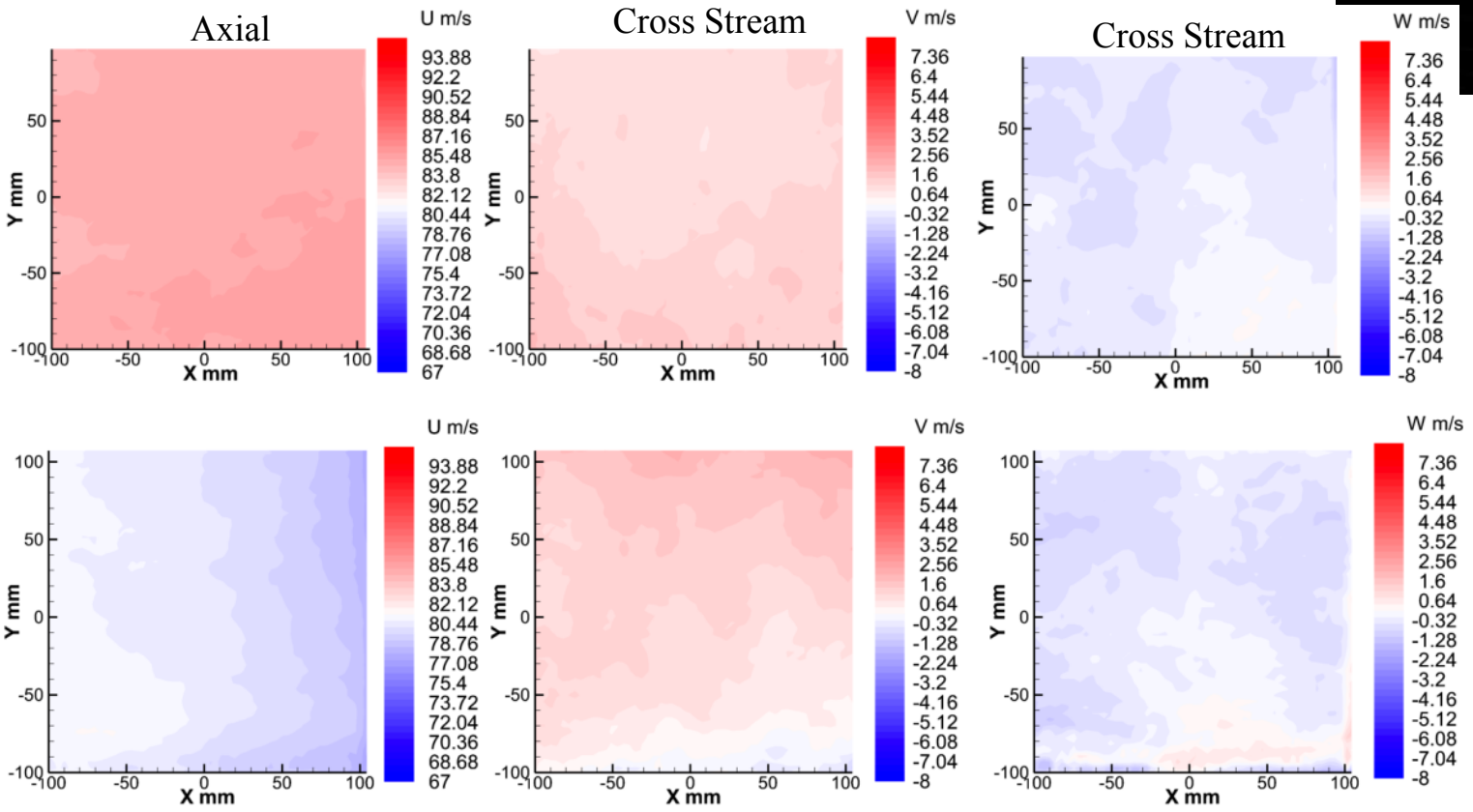
Two-Chute Drag Versus Dynamic Pressure



Example of PIV Results



Capsule Only



Parachute Present

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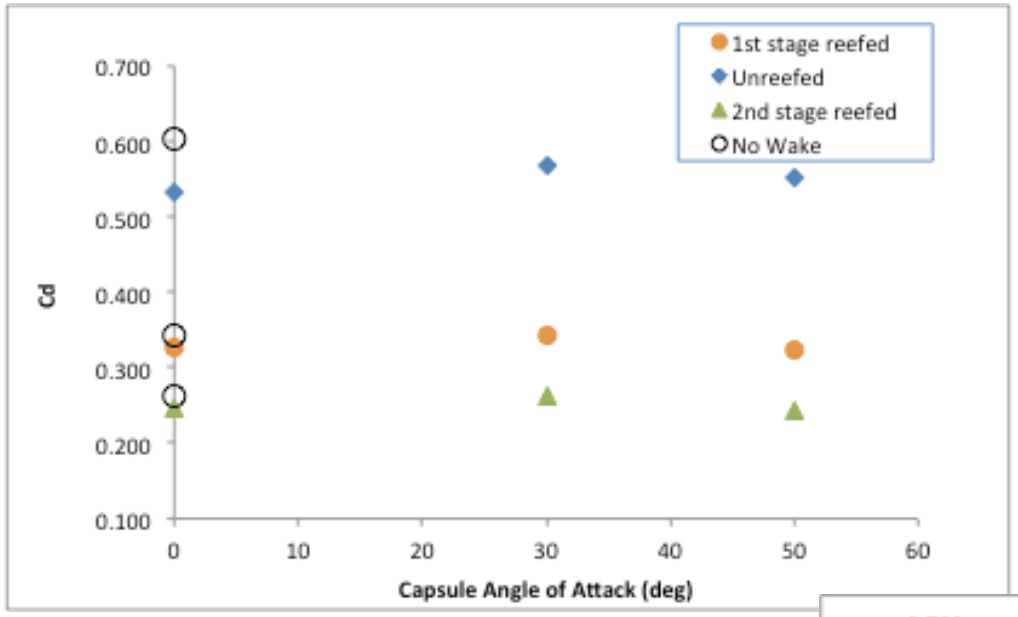
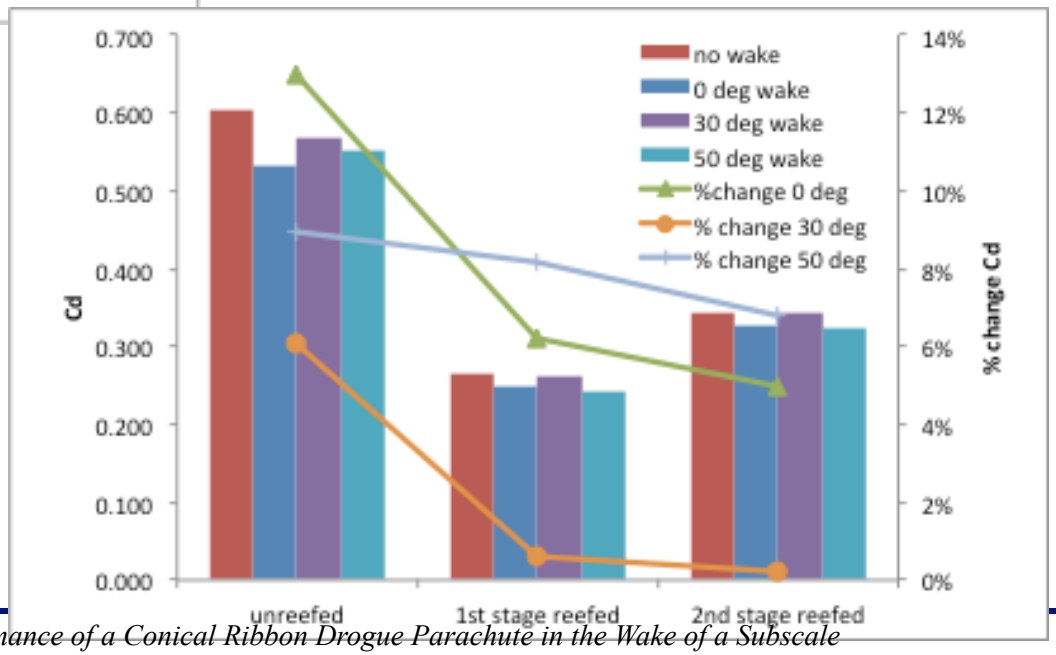
Comparison of Wake Effect and No Wake





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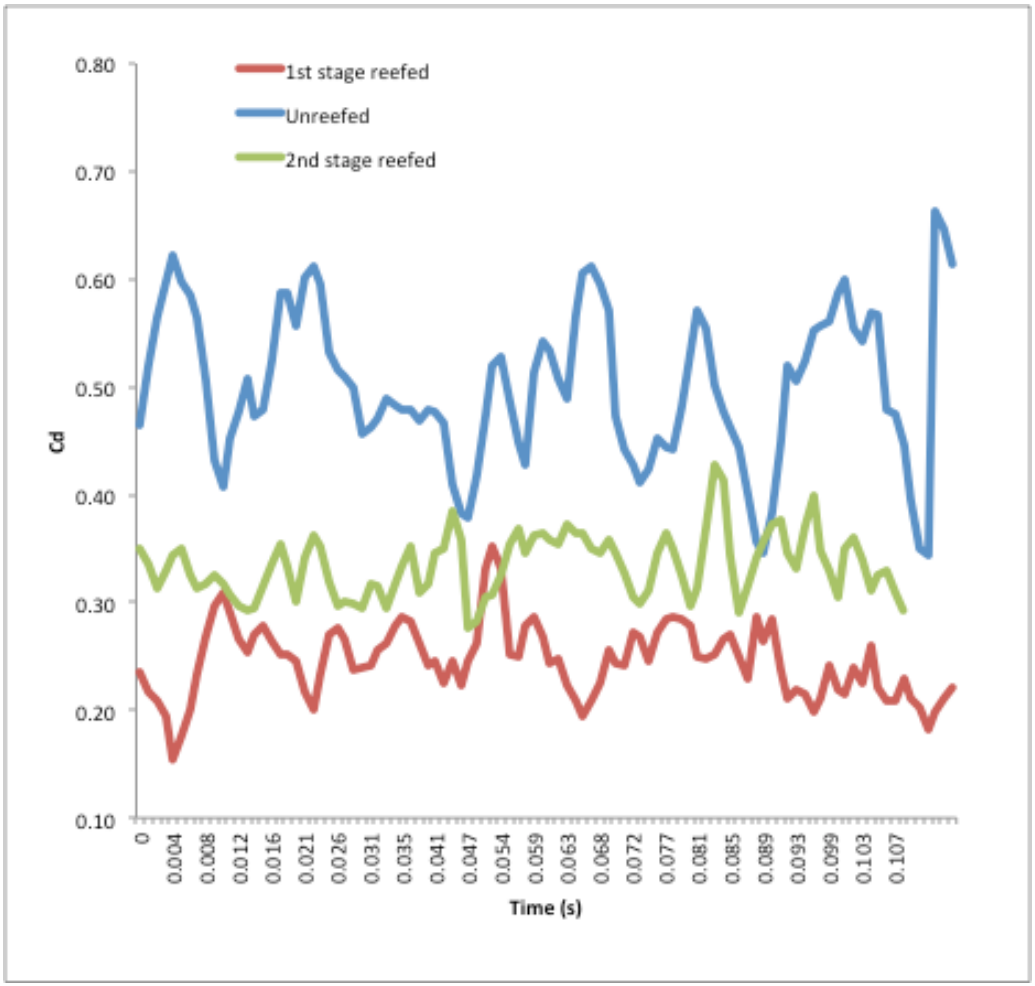
Frequency Analysis

- Frequency component of parachute load in the 50 to 70 Hz range for cases with capsule present



Conclusions

- Full matrix of aero data for a range of parameters
- Subscale capsule drag is within 2% of full scale
- Subscale parachute drag is within 5% of full scale
- Parachute inflated shapes are similar for unreefed and reefed configurations
- Capsule wake induces large load fluctuations but on average a reduced drag coefficient
- Significant work remaining to reduce the dataset